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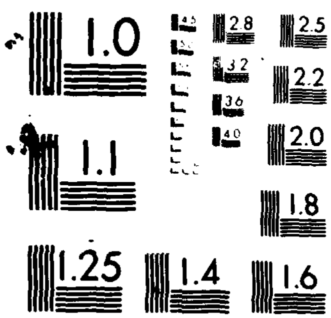

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FEASIBILITY ANALYSIS IN SMALL HYDROPOWER PLANNING

by

DARRYL W. DAVIS

BRIAN W. SMITH

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The Hydrologic Engineering Center, Corps of Engineers, has prepared a manual entitled "Feasibility Studies for Small Scale Hydropower Additions". The manual provides technical data and procedural guidance for the systematic appraisal of the viability of potential small hydropower additions and focuses upon the concepts, technology, and economic and financial issues unique to these additions.

This paper presents the significant findings and conclusions that became evident from the studies performed during preparation of the manual.

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FEASIBILITY ANALYSIS IN SMALL HYDROPOWER PLANNING [1]

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INTRODUCTION

The Hydrologic Engineering Center, Corps of Engineers, has prepared a manual entitled "Feasibility Studies for Small Scale Hydropower Additions". The manual provides technical data and procedural guidance for the systematic appraisal of the viability of potential small hydropower additions and focuses upon the concepts, technology, and economic and financial issues unique to these additions. The manual, designed to aid in the performance of reconnaissance studies (should a feasibility study be performed?) and feasibility studies (should an investment commitment be made?), was developed for use by public agencies (federal, state, and local), public and private utilities, and private investors.

The manual includes data and discussions on the topical subjects of cost escalation in economic and financial analysis, feature component selection for reconnaissance and feasibility levels of study, and time, costs, and resources required to perform the investigations. This paper presents the significant findings and conclusions that became evident from the studies performed during preparation of the manual (HEC, 1979).

DEFINITION OF SMALL HYDROPOWER

Small hydro projects include installations that have 15,000 kW or less capacity. "Small hydro" and "low head hydro" are not synonomous. Small

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[1] Presented at the Conservation and Utilization of Water and Energy Resources Conference, American Society of Civil Engineers, 8-11 August, 1979, San Francisco, California.

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hydro as defined has been an informal breaking point used for various federal and other agency statistical tabulations and informal communications. The concept has now been defined by law (PL 95-617, 95th Congress 1978) to be 15,000 kW for purposes of special handling for licensing, loans, implementation incentives, and other promotional programs. Low head hydro is a term associated with a research and development program managed by the Department of Energy that is designed to advance the technology for generating hydropower from sites with heads of less than 20 meters (66 feet).

FACTORS IMPORTANT FOR FEASIBILITY

The reasons underlying the major national attention that is focused on small hydro is important in establishing the conceptual base for establishing a feasibility methodology. Simply stated, they seem to be: the national desire to move to energy independence, the current national concern for resource conservation, the potential for quick results from public and private efforts (an increasingly rare commodity in today's world), and the demand for non firm energy, presently valued in many areas at 15 to upwards of 40 mills per kilowatt-hour as compared to 1 to 2 mills per kilowatt-hour several years ago. The character of small hydro is such that the marketable output will most often only be energy with little, if any, dependable capacity. This means the value of small hydropower will be primarily due to fuel and other operating cost savings and not due to offsetting the need for new power plants to supply capacity.

The feasibility of projects is expected to be quite sensitive to site specific conditions, e.g., the quantity of power produced will not likely support an extensive array of ancillary features such as long transmission lines, access roads, or significant site preparation, etc. The nature of the market area load characteristics and present generating facilities servicing the load are critical elements in valuing power output. Areas served with major fossil fuel base plants or systems with high operating cost plants, operating at the margin will be more attractive for small hydro development. A significant issue of project feasibility is that investigation, design, construction management, administration and contingencies (the non-hardware elements of a project) are a major cost burden. Figure 1 schematically

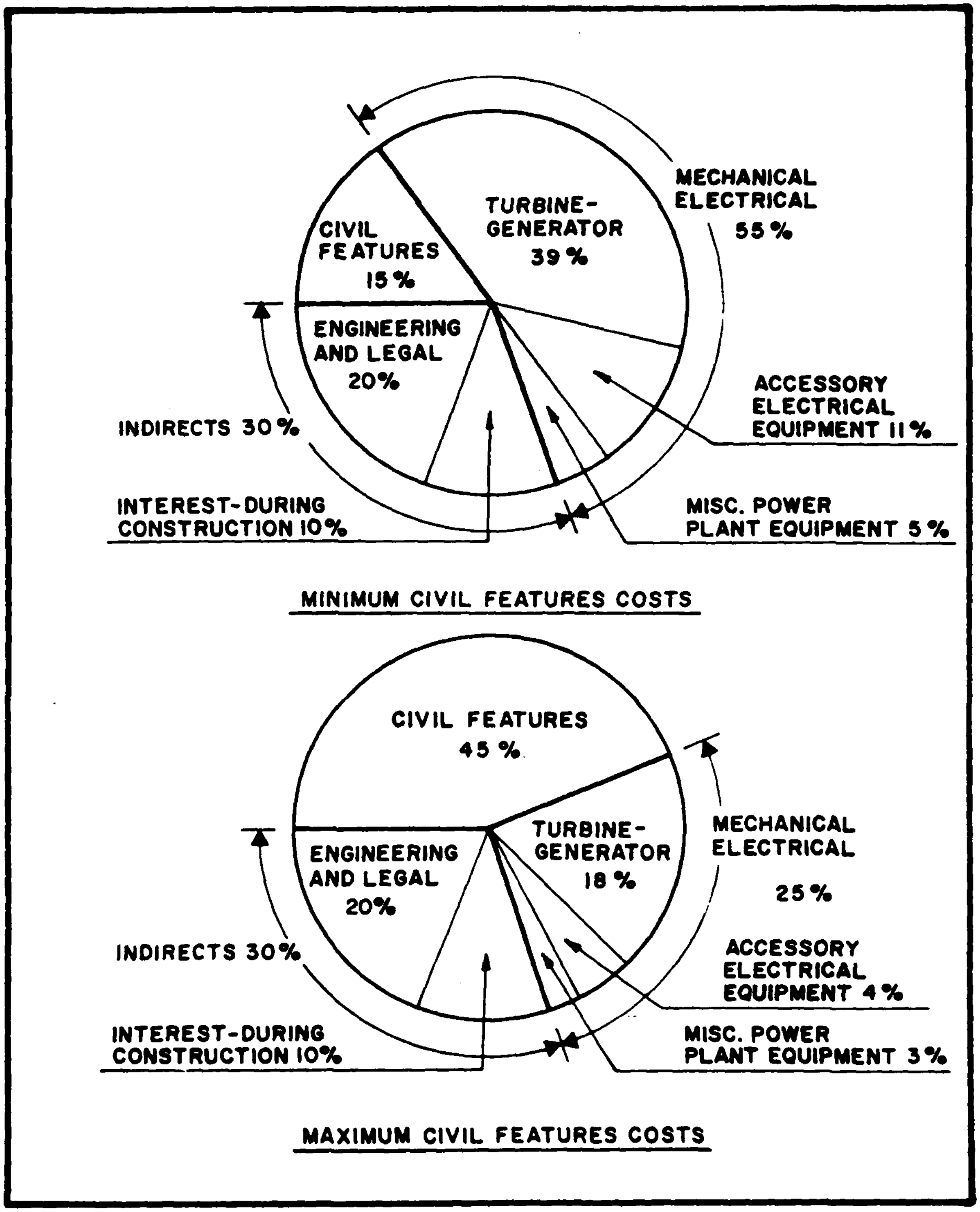


Figure 1. Range of Civil Features Costs
(Vol. 6 HEC, 1979)

illustrates the cost elements in small hydro projects.

PLANNING STUDIES

Several types of studies varying in scope, detail, and intended client are performed to determine the desirability of public and private implementation of hydropower proposals. This manual has adopted the standard sequence of preconstruction studies commonly followed in private and international practice. They are "reconnaissance" (should a feasibility study be performed?), "feasibility" (should an investment commitment be made?), and "definite plan" (the collective group of studies that are performed between an implementation commitment and construction initiation that result in permit applications, preparation of marketing agreements and financial arrangements, and definition of design parameters). The manual is designed to aid in the execution of the reconnaissance and feasibility studies. The manual defines a reconnaissance study as . . . "a preliminary feasibility study designed to ascertain whether a feasibility study is warranted: and feasibility study as . . . "an investigation performed to formulate a hydropower project and definitively assess its desirability for implementation."

RECONNAISSANCE STUDY

The execution of a feasibility study can be a significant investment in time and resources suggesting that a decision to proceed with a study should be based on a finding that a potentially viable project proposal will be forthcoming. The reconnaissance study is designed to reduce the potential chance of a subsequent unfavorable feasibility finding and maximize the potential for identifying and moving forward the attractive projects. The reconnaissance study is a relatively complete small scale feasibility study in which the issues expected to be important at the feasibility stage are raised. The finding of a reconnaissance study should be either a positive recommendation to proceed with a feasibility study which would include a study plan and method of accomplishment, or a recommendation to terminate further investigations.

Project Formulation

The strategy for performing a reconnaissance study is first to perform a preliminary economic analysis and then identify and assess the issues that may be critical to implementation. The components identified as important in reconnaissance studies are shown in Figure 2. The formulation of project features and determination of costs was determined to be a critical and major task. The recommended project formulation strategy is to select several installed capacities , say at 15%, 25% and 35% flow exceedence values, and carry these through the preliminary economic analysis. The procedures developed for performing the cost estimates for construction, site acquisition, operation and maintenance, and engineering and administration for the feasibility study were judged to be too detailed for a reconnaissance study. To facilitate reconnaissance estimates, the information for the feasibility analysis was consolidated into one chart and table. Figure 3 provides a basis for estimating the major share of construction costs for items that are governed by capacity and head, e.g., turbine and generator, powerhouse, and supporting electrical/mechanical equipment. The figure was developed by studying the generator and powerhouse costs for a variety of turbine types for a complete set of head/capacity values. Table 1 contains reconnaissance cost factors for penstock, tailrace, switchyard equipment, and transmission line. The user is cautioned that the least cost criteria governed so that site issues of space and configuration, and generation issues of performance ranges were not considered. The data, however, should be adequate for reconnaissance estimates. An additional allowance of up to 20% should be added to the cost determined to cover investment items that are not incorporated in the chart and table such as land acquistions, access roads, and special control equipment. Projects approaching the upper limits of capacity (15MW) probably warrant using the more detailed and specific charts in the manual even for the reconnaissance estimate.

Since reconnaissance cost estimates are also needed for the nonphysical works cost items, an allowance for unforseen contingencies ranging from 10% to 20% should be added to the sum of the construction cost, the value

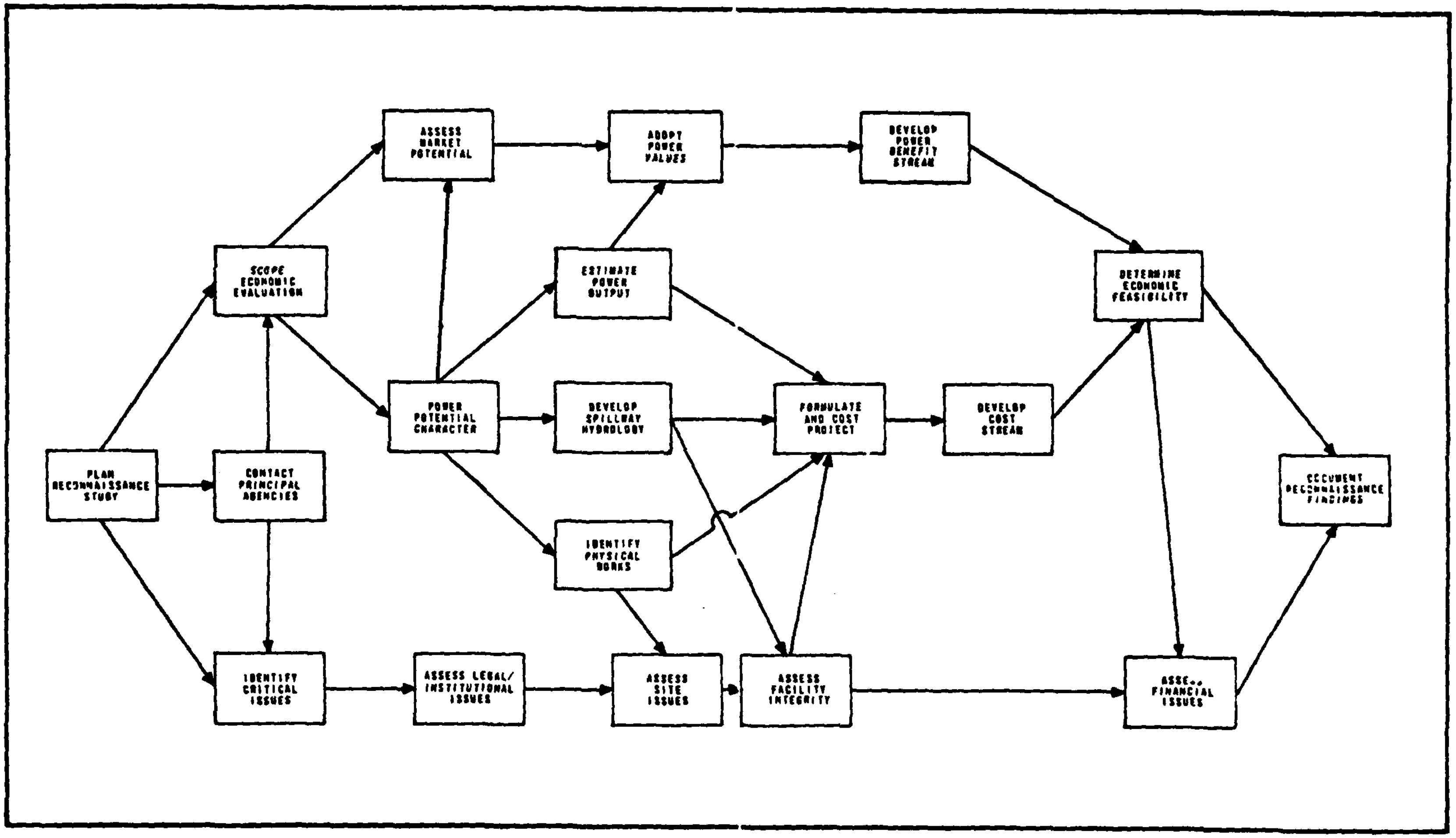
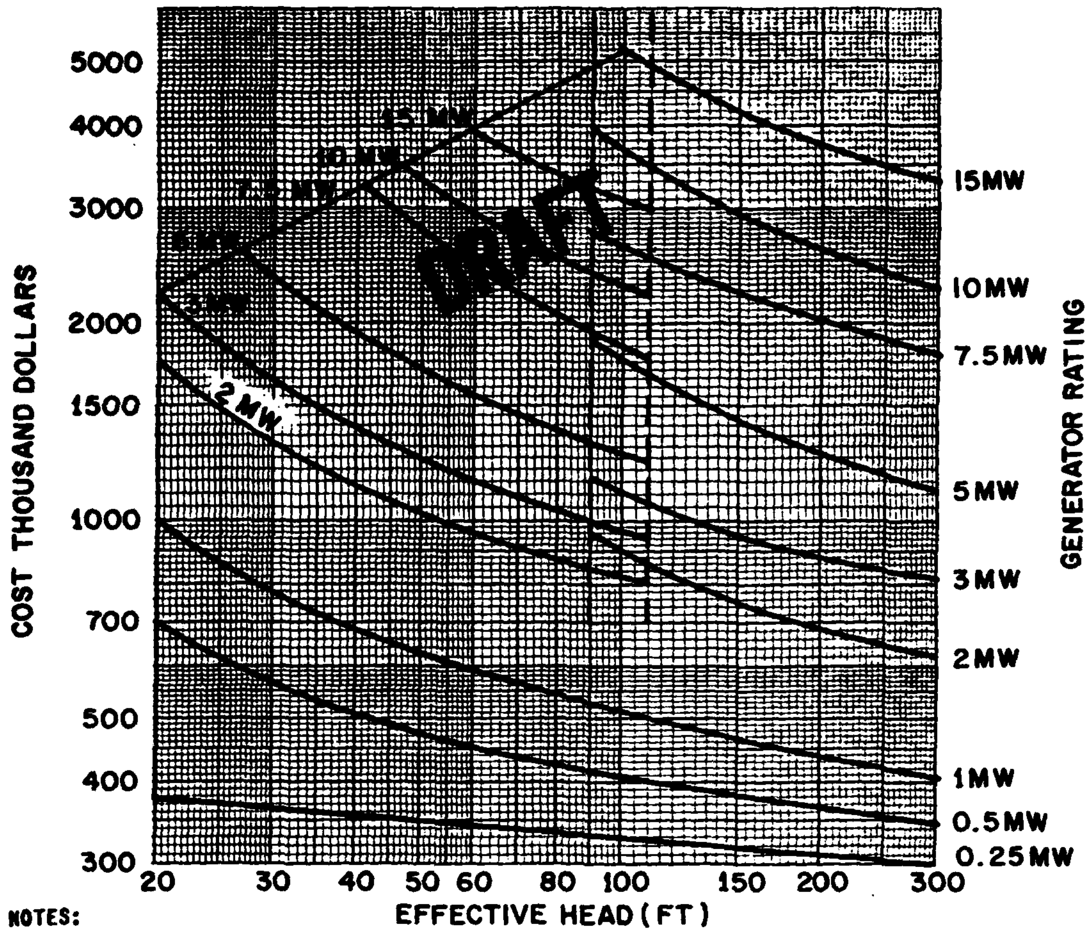


Figure 2. Reconnaissance Study Components
(Vol. 1 HEC, 1979)



NOTES:

1. Estimated costs are based upon a typical or standardized turbine coupled to a generator either directly or through a speed increaser, depending on the type turbine used.
2. Costs include turbine/generator and appurtenant equipment, station electric equipment, miscellaneous powerplant equipment, powerhouse, powerhouse excavation, switchyard civil works, an upstream slide gate, and construction and installation.
3. Costs not included are transmission line, penstock, tailrace construction, switchyard equipment.
4. Cost base July 1978.
5. The transition zone occurs as unit types change due to increased head.
6. For a Multiple Unit powerhouse, additional station equipment costs are $20,000 + $58,000x(n-1) where n is the total number of units.
7. Data for this figure was obtained from figures and tables in Volumes V and VI.

Figure 3. Power Features Cost - Reconnaissance (Vol. 1 HEC, 1979)

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TABLE 1

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MISCELLANEOUS RECONNAISSANCE ESTIMATE COSTS*

PENSTOCK COST

Effective Head (Ft)	10	20	50	100	200	300
Cost Index (CI)	960	480	200	110	55	35

Installed Cost = CI x Penstock Length(ft) x Installed Capacity(MW)

TAILRACE COST

Construction Cost = $15,000 fixed plus $200 per lineal foot

SWITCHYARD EQUIPMENT COST

(Thousand Dollars)

Plant Capacity	Transmission Voltage 13.8	34.5	69	115
1 MW	50	60	--	--
3 MW	85	100	120	175
5 MW	110	125	150	210
10 MW	150	170	210	280
15 MW	185	220	250	320

TRANSMISSION LINE COST

(Thousand Dollars)

Plant Capacity	Miles of transmission line 1	2	5	10	15
0.5 MW	30	60	150	--	--
5 MW	45	80	160	320	500
10 MW	60	100	180	380	600
15 MW	80	140	230	460	700

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* (Vol. 1 HEC, 1979)

depending upon a judgement as to the uncertainties. Indirect costs of 25% are recommended to be added for investigation, management, engineering, and administration costs that are needed to implement the project and continue its service. Operation and maintenance costs can vary considerably depending on present staff resources of the project proponent, the site proximity to other sites, and the intended degree of on-site operation requirements. An annual value of 1.5% of total costs is suggested as a base value; however, the value used should not be less than a base value, suggested as $20,000 per year and may range upwards of 4% if the project proponents can not efficiently integrate the plant into their work program.

Power Values

The determination of value of power was an item carefully considered during preparation of the manual. The power value needed is the value that the project proponent could reasonably expect to receive for the sale of the generated energy and that of the dependable capacity, if any exists. A suggested procedure is that reconnaissance values be adopted from values solicited from the regional Federal Energy Regulatory Commission (FERC) office in the case of potential sale to utilities, municipal organizations and cooperatives, or be extracted from existing rate shcedules (avaluable from local utility offices) in the case of potential sale to a private industrial buyer. A benchmark value that can often be used to value energy is the fuel replacement cost that is reported by utilities to the FERC Regional Offices. A generous value in the range of 20 to 40 mills per kWh is considered reasonable in light of presently escalating fuel and operation costs.

Economic Feasibility

Economic Feasibility is positive when the benefits exceeds the costs. The manual encourages adoption of the Internal Rate of Return method of characterizing project feasibility. The Internal Rate of Return is the discount rate at which the benefits and costs are equal, e.g., the discount rate at which the benefit to cost ratio is unity. Use of the method avoids the need at the reconnaissance stage to adopt a discount rate and also provides an array of economic feasibility results. An example computation and

display is included in Figure 4. To perform the analysis several discount rates are selected and the total investment cost in annualized for each rate and added to the annual operation and maintenance cost to obtain the total annual cost. The benefit is computed on an annual basis by multiplying the yearly generation by the value of energy. A benefit to cost ratio is determined for each total annualized cost which is then plotted relative to its respective discount rate. A curve is drawn connecting the plotted points and the Internal Rate of Return is the discount rate where the curve intersects the line representing a benefit to cost ratio of unity (see example).

FEASIBILITY STUDY

The feasibility study is designed to formulate a viable small hydro project, develop an implementation strategy, and provide the basis for an implementation commitment. The addition of small hydropower generation to an existing facility is, with few exceptions, a single purpose project planning task. The significant legal, institutional, engineering, environmental, marketing, economic and financial aspects are to be identified, investigated, and definitively assessed in support of an investment decision. The objective is to formulate a power addition project that is economically attractive and consistent with modern concepts of resource planning and management. The findings of a feasibility study should be whether or not a commitment to implementation is warranted, and should the finding be positive, define the steps needed to assure implementation.

The selection of the installed capacity, the number of units, and the supporting ancillary physical works are the specific objective of project formulation. The target of small hydro project formulation is to develop one or more proposals that have the greatest economic value consistant with the array of constraints that modify the attractiveness of a purely economic formulation. Two issues were singled out for expanded discussion in the feasibility study section of the manual. They were refinement of alternatives and development of costs for both the economic and financial analysis.

PLANT CHARACTERISTICS:

RUN OF RIVER

Head	= 90 feet	Penstock	= 115 feet
Capacity	= 8 MW	Transmission Line	= 2.5 miles @ 34.5 kV
Efficiency	= 90%	Economic Life	= 50 years
Dependable Capacity	= 0 MW	Evaluation Date	= July 1979
Tailrace	= 250 feet	Average Yearly Energy Generated	= 35×10^6 kWh

INVESTMENT COST: ($1,000)

Turbine, Generator and Civil (Figure 4-2)		2,000
Additional Station Equipment (Multi-Unit)		None Required
Penstock (Table 4-2)	(128 x 115 x 8)	118
Tailrace (Table 4-2)	(15,000) + (200 x 250)	65
Switchyard Equipment (Table 4-2)	(8 MW @ 34.5 kV)	152
Transmission Line	(8 MW @ 2.5 miles)	105
Dam Rehabilitation (Integrity)		None Required
Other (Access, Fish Passage, Miscellaneous Site Construction)		None Required
SUBTOTAL		2,440
Escalation (July 78 to July 79 - Figure 6-1, Vol. VI - Ratio: 2.52/2.28)		2,697
Contingencies at 10%-20%	(Used 15%)	405
SUBTOTAL		3,102
Indirect @ 25%		776
TOTAL INVESTMENT COST		3,877

ANNUAL COST: ($1,000)

Annualized Investment Cost is a function of discount rate and economic life of a project and is computed by multiplying the Total Investment Cost by the Capital Recovery Factor for the discount rate and economic life selected. See Table Below

Operation and Maintenance (O&M) Cost = ($20,000 Minimum or 1.5%-4%)(Used 3%) 116

TOTAL ANNUAL COST (Sum of Annualized Investment Cost and O&M Cost) = See Table Below

BENEFIT ESTIMATE:

Capacity Benefit (Dependable Capacity x Value of Capacity) = None

Energy Benefit (Average Annual Energy Generated x Value of Energy) = See Table Below

TOTAL ANNUAL BENEFIT (Sum of Capacity Benefit and Energy Benefit) = See Table Below

COST AND BENEFIT COMPUTATION TABLE

DISCOUNT (INTEREST) RATE (%)	CAPITAL RECOVERY FACTOR	ANNUALIZED INVESTMENT COST[1] ($1,000)	TOTAL ANNUAL COST[2] ($1,000)	BREAK EVEN ENERGY VALUE[3] (Mills/kWh)	TOTAL ANNUAL BENEFIT[4] ($1,000)	NET BENEFIT[5] ($1,000)	B/C RATIO[6]
12	.12042	467	583	16.7	770	187	1.32
14	.14020	544	660	18.9	770	110	1.17
16	.16010	621	737	21.1	770	33	1.04
18	.18005	698	814	23.3	770	-44	0.95
20	.20002	775	891	25.5	770	-121	0.86

NOTES:

[1]Capital Recovery Factor x Total Investment Cost ($3,877).

[2]Annualized Investment Cost + O&M Cost ($116).

[3]Total Annual Cost ÷ Average Annual Energy Generated (35×10^6 kWh).

[4]Average Annual Energy Generated (35×10^6 kWh) x Value of Energy (taken as 22 mills/kWh) plus the Capacity Benefit (equal to zero for this example).

[5]Total Annual Benefit ($770) - Total Annual Cost.

[6]Total Annual Benefit ($770) ÷ Total Annual Cost.

Figure 4. Reconnaissance economic feasibility example (Vol I, HEC 1979)

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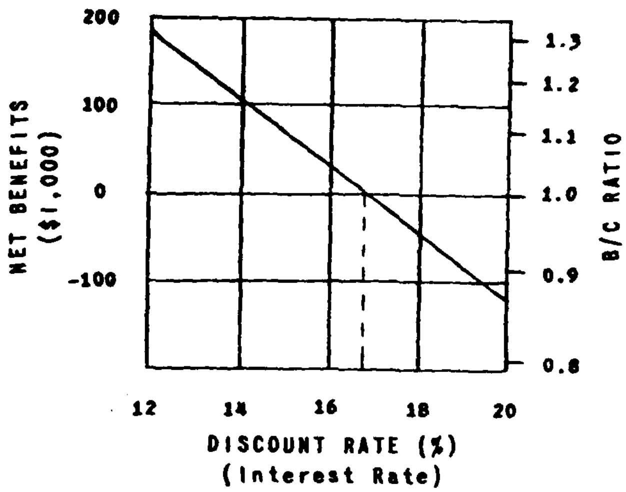
INTERNAL RATE OF RETURN:

The Rate of Return on Investment is the interest rate at which the present worth of annual benefits equals the present worth of annual costs (Net Benefits equal to zero or Benefit/Cost Ratio equal to unity). The internal Rate of Return is 16.8%.



BREAK EVEN ENERGY VALUE:

A similar alternative return type graph is presented here based on the concept of the Break Even Energy Value. This is the value of energy (mills/kWh) which makes annual costs equivalent to the annual return. It is determined by dividing the Average Yearly Generation (kWh) into the Total Annual Cost ($) for each discount rate selected as shown in the table above. At 22 mills/kWh, the Rate of Return is identical to that derived above.

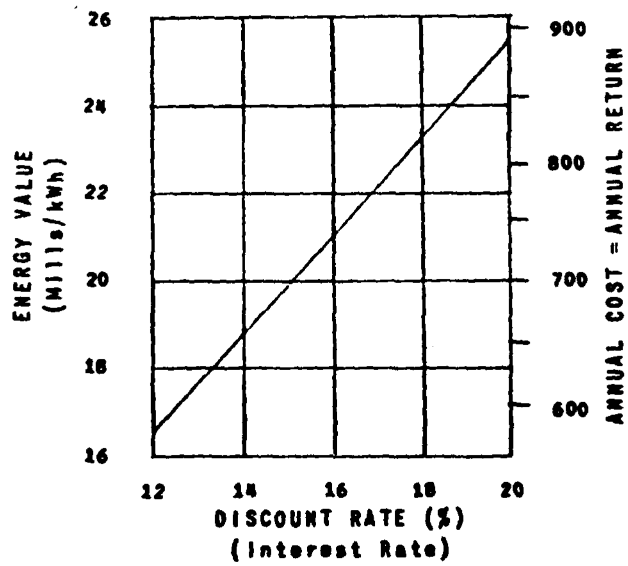


Figure 4 continued. Reconnaissance economic feasibility example

Refinement of Alternatives

The significant interacting factors in the formulation of a small hydro project are the nature of flow/head availability, the performance characteristics of the turbine equipment, and the powerhouse structure needed to accommodate the specific generating equipment. The amount of energy that can be generated is dependent upon the range of flow that can be passed through the turbine and upon the head variation. The range of flow that can be utilized is therefore a function of the installed capacity, type of turbine (operating range and efficiency characteristics), and the number of units. Each of these variables affects the size and shape of the powerhouse.

A project formulation strategy that progresses through three progressive stages of feature sizing and selection is suggested. The first stage, essentially performance of a reconnaissance formulation as discussed previously, yields a preliminary estimate of the project installed capacity. The second stage incorporates machine performance characteristics in the formulation of several refined alternatives and yields a selection of the number and type of turbine units that thus consider site conditions and tradeoffs between unit performance and energy generated. The final stage concludes the project formulation by examining the performance of the more promising one or more alternatives in a sequential power routing analysis.

Hydrologic parameters play an important part in refinement of alternatives. Initially and during the first stage, and perhaps the second, flow-duration techniques are judged to be generaly adequate. Duration curve analysis requires the use of a single value (weighted) for head and a single value (average) for efficiency. Refinement occurs with the use of a continuous record of stream flow and performance of sequential power routings. This procedure assures that important sequential issues of varying upstream and downstream water levels, machine performance, and flow passage by the site are properly incorporated in the analysis. The more complete simulation will trace the turbine performance and may result in slightly higher or lower power and energy output estimates. The array of refined project formulations are then subjected to full feasibility analysis.

Economic Analysis Cost Consideration

In the manual, economic and financial analysis have been carefully defined as having distincly different purposes, and consequently, distinctly different (although very much similar) cost data. Economic feasibility analysis compares economic costs with project economic benefits while financial feasibility analysis develops the specific cash flow and assesses financing and repayment issues. The economic comparison is properly made using a common value base, (e.g., dollar avalues as of the study year). Federal government policies have generally resulted in fixing price levels for valuing future costs and benefits in value terms as of the study date as well and the time frame commonly used for cost/benefit analysis begins the first year of project operation and extends through the project economic life. The alternative convention often adopted in the private sector is to state all project costs and benefits in dollar values as of the initial year of operation. Since small hydro projects are expected to be implemented in short time frames, the time and year statement of dollar values should not be critical.

The inclusion of cost and value changes in economic feasibility analysis must be handled with care. In principle, a price level change economic analysis should forecast the change in value for all aspects of the feasibility assessment, both the cost side and its several components, and the benefit side (e.g., alternative fuel costs) and its several components. The cost and benefit streams are then constructed from these forecasts and the feasibility assessment performed. The usual result of including cost and value escalation in projects such as small hydro (large initial cost followed by small O & M, and long stream of project benefits) is to make them appear more economically attractive, e.g., benefits grow with time while costs increase slightly based on O & M. The impetus for including value changes is the conviction that benefits will continue to rise knowing that some benefit elements are increasing more rapidly than the general inflation rate, e.g., fossil fuel costs. The argument is that ignoring these value shifts leads to incorrect decisions, (e.g., the project may appear infeasible when it should be found to be feasible) even though theoretically, (Howe, 1971) inclusion of general price rise (inflation, not differential cost escalation) does not affect the feasibility determination.

The argument against including price level change and/or general cost escalation in economic feasibility analysis is that change in price forecasting is fraught with pitfalls that are both institutionally and technologically dependent. The resulting analysis thus often becomes suspect and a candidate for subjective manipulation, i.e., a means of justifying projects. If cost and value change analysis are adopted for the economic analysis, considerable care should be taken to rigorously observe the basic principles and to document the critical value change forecasts.

Financial Analysis Cost Considerations

Financial feasibility analysis develops, among other data, the specific cash flow characteristics (dollars in and out of the accounts) of the project. The need is to forecast the amount and timing of cash outflow and revenue income as accurately as possible. The cash flow analysis is usually constructed for the project implementation period, the first year of operation often being critical to project cash reserves. To perform the analysis, the construction costs are indexed to the actual date of contract award; interest during construction is added along with recurring costs (operations and maintenance) escalated based on increased costs to service aging equipment and on anticipated general cost inflation; and the revenue stream is adjusted based on anticipated power sale contract provisions for payment of project power. If there were no cost inflation, no borrowing required, and if project revenues captured all project benefits exactly, the economic cost and benefit streams and the financial cost and revenue cash flow streams would be identical.

TIME, COST, AND RESOURCES FOR FEASIBILITY AND RECONNAISSANCE STUDIES

The time, costs, and manpower resources required to perform reconnaissance and feasibility studies for small hydroelectric power plant additions varies depending on expected plant size, site conditions, specific scope and depth of study, and availability of information (basic data and prior studies). Each of the five supporting volumes in the manual provides general guidance on this topic in their respective subject areas. The American

Society of Civil Engineers has published general guidelines for compensation for the performance of engineering services (ASCE, 1972). Analysis of these guidelines in light of recent feasibility study experience suggests that feasibility study costs, noting the fairly specialized nature of several of the issues important to small hydro, should range from 1.5% to 3% of estimated construction cost. Reconnaissance studies, "mini feasibility studies", estimated as 10% of feasibility study costs, would therefore range from 0.15% to 0.3% of estimated construction cost. A reconnaissance study for a 1 MW plant might cost approximately $3,000 (or about 10-15 man-days) and for a 15 MW plant, perhaps $12,000 (45 to 60 man-days). Using 2.5% as conservative estimate for feasibility study costs results in study costs ranging from $25,000 (80 to 110 man-days) for a 1 MW plant to $150,000 (600 to 750 man-days) for the larger plants. The time required to perform the feasibility study could range from 60 days for the small, relatively simple power addition to upwards of 6 to 9 months for larger more complex projects.

The participating professionals for a feasibility study include civil, electrical and mechanical engineers, power economists, and especially for private proponent projects, the services of financial specialists. Projects that significantly alter the flow regime or physical environment will likely need the services of water quality and fish and wild life specialists. The participating professionals for a reconnaissance study would likely include civil, mechanical, and electrical engineer, and power economist for larger proposed projects. Reconnaissance investigations of smaller projects may require more versitility in fewer professional such as, experienced engineer and economist.

STATUS OF MANUAL

The manual is presently (July 1979) undergoing final editing, typesetting, and printing. Priority distribution is planned for late August and general public distribution in October.

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3. Howe, Charles W., "Benefit Cost Analysis for Water System Planning", American Geophysical Union, Water Resources Monograph 2, 1971.

4. The Hydrologic Engineering Center (HEC), Davis, CA., 95616, Feasibility Studies for Small Hydropower Additions, 6 Volumes, July 1979.

TECHNICAL PAPERS

Technical papers are written by the staff of the HEC, sometimes in collaboration with persons from other organizations, for presentation at various conferences, meetings, seminars and other professional gatherings.

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\# 1 Use of Interrelated Records to Simulate Streamflow, Leo R. Beard, December 1964, 22 pages.

\# 2 Optimization Techniques for Hydrologic Engineering, Leo R. Beard, April 1966, 26 pages.

\# 3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs, Leo R. Beard, August 1965, 21 pages.

\# 4 Functional Evaluation of a Water Resources System, Leo R. Beard, January 1967, 32 pages.

\# 5 Streamflow Synthesis for Ungaged Rivers, Leo R. Beard, October 1967, 27 pages.

\# 6 Simulation of Daily Streamflow, Leo R. Beard, April 1968, 19 pages.

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